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Testing innovation systems theory using Qualitative Comparative Analysis☆

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ABSTRACT

Systematic approaches to understanding innovation are common, but these approaches still need testing as theories. This study aims to fill that gap by constructing sectoral and technological innovation-system failure models as theories and by testing those models using a multiple case study and fuzzy set qualitative comparative analysis. Both theories predict innovation system performance. Qualitative comparative analysis proved useful in both constructing and testing theory.

1. Introduction

Innovation systems (IS) thinking is becoming increasingly influential (Manjón & Merino, 2012). IS attempts to explore the complexity of innovation processes, and seek to understand the necessary environments and interactions for successful innovation. Scholars propose IS as conceptual frameworks and attempt to maintain conceptual ambiguity to encompass all important factors in innovation (Edquist, 1997). IS proponents judge IS approaches as useful without explicitly stating a theoretical position or rigorously evaluating the claims to successful intervention. In particular, many authors use one of two theoretical models to explore IS failure (Bergek et al., 2008; Klein Woolthuis et al., 2005). Scholars use these frameworks, conceptual models, or approaches for analysis, diagnosis, and policy development; however, no studies test those models' ability to explain innovation.

This research tests two IS failure approaches as theoretical models on innovation, using Qualitative Comparative Analysis (QCA) (Rihoux et al., 2013). QCA is consistent with the case-study tradition and provides for cross-case analysis with logical rigor (Berg-Schlosser et al., 2009; Yin, 2009). QCA can identify conditions causally related to an outcome, while acknowledging the possibility that multiple paths may lead to that outcome (Rihoux, 2013). QCA allows the statement and testing of theory using set theory. Woodside (2013) points out the value of using QCA for building and testing theory, the generation, and consideration of multiple combinations of conditions on the outcome, and value of considering the individual case. The application of case-study methodology is consistent with the empirical approach of IS scholars.

This study employs set theoretic methods (QCA) to define and test theories of innovation system failure. In QCA terms, the specific question is whether all the conditions the theories propose for the outcome of innovation system performance (ISP) are necessary and sufficient. This study is the first study that formally states ISP frameworks as theories and that tests those theories through multiple case studies.

2. Theory

IS thinking first appears in the 1990s as an attempt to "explain—and perhaps influence—the processes of innovation" (Edquist, 1997, p. 2). At that moment, scholars see the activities occurring within IS as broadly aiming at the creation, diffusion, and exploitation of knowledge and ideas. Yet an IS extends beyond research activities to organizational competence within firms, capacity for change in organizations, services and institutions therefore maximizing innovation outcomes (Edquist, 2005).

The above concepts of IS describe conditions that may, in some combination, lead to successful innovation outcomes. This work compares theories of failure proposed for sectoral and technological systems of innovation. Sectoral IS (SIS) apply to a particular product or service field, whereas technological IS (TIS) consider technological innovation free of other interference or limitations.

SIS focus is on firms in an innovation environment that has product or service boundaries. Scholars describe SIS models "composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation,

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production and sale of those products" (Malerba, 2004, p. 16). SIS are a flexible, holistic and interdisciplinary approach to understanding innovation of products and services within an environment that multiple actors and institutions influence (Edquist, 2005; Klein Woolthuis et al., 2005).

TIS is a "network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz, 1991, p. 94). A TIS contains all the components necessary to influence the innovation process for a particular technology (Bergek et al., 2008) and analysis may proceed from consideration of customers, products and/or technologies (Carlsson et al., 2002).

Sectoral and technological IS literatures offer the possibility of understanding how and why investment may fail to lead to innovation. The IS literature rejects market failure as the sole reason for failure of innovation. Instead, studies consider the concept of innovation system failure to result from imperfections in elements of the innovation system (Klein Woolthuis et al., 2005). In QCA terms, research defines a number of conditions resulting in ISP outcome. These conditions may be in a state of imperfection or failure, and may thus prevent ISP, making innovation more difficult or unlikely.

Within the SIS literature, a seminal paper on diagnosis of innovation system problems is that of Klein Woolthuis et al., (2005), whereas within the TIS literature, Bergek et al. (2008) propose an approach to the understanding IS functions. Neither study claims to develop or propose theory; rather these studies claim approaches to analysis and policy intervention drawing on empirical studies of their own and others. To trust the ability of these approaches to define the operation of an effective IS, a careful analysis of these approaches is necessary to determine the theory they propose, the claims that they make, and the validity of the approaches.

The structural theoretical model (S theory) of ISP (Klein Woolthuis et al., 2005) builds on the assumptions of SIS: that innovation does not occur in isolation, institutions are critical and evolutionary processes play an important role in determining innovation outcomes. The theory acknowledges that imperfections can occur and seeks to define these system imperfections. Five conditions that can affect ISP are institutions, infrastructure, interactions, actor capability (Klein Woolthuis et al., 2005) and market factors (Klein Woolthuis, 2010). Both Bergek et al. (2008) and Wieczorek and Hekkert (2012) refer to this approach as "structural". The authors of this structural approach claim the ability to analyze and evaluate IS, to identify the causes of failure, and to provide justification for policy intervention.

The functional theoretical model (F theory) of ISP (Bergek et al., 2008) builds on the assumptions of TIS and provides another approach to analysis of ISP. Bergek et al. claim that certain processes, or functions, need to occur for ISP. Wieczorek and Hekkert (2012) identify Bergek et al.'s work as a "functional" approach. These authors acknowledge the structural components of the TIS and identify 7 key functions (conditions) operating within TIS: entrepreneurial experimentation, knowledge development, knowledge dissemination, direction of the search, market formation, provision of resources, gaining acceptance. This theory of functional problems aims to help policy makers. Several scholars use both theoretical models to analyze ISP (Klerkx & Leeuwis, 2009), but rigorous testing of the theories is lacking.

The hypothesis under study is that firms must meet all conditions that the S and F theories identify to achieve ISP. In set theoretic terms: a case must be within the intersection of sets in which all conditions of both S and F theories are operational for ISP to be adequate so that innovation (I) may occur. ISP is necessary, but not sufficient for the outcome of innovation (I). In formal notation (Schneider & Wagemann, 2012),

$$S_1 * \ldots S_n * F_1 * \ldots F_n \rightarrow ISP \leftarrow I$$

where

$S_1 \ldots S_n$	represents the range of structural theory conditions defined above ($n = 5$)
$F_1 \ldots F_n$	represents the range of functional theory conditions defined above ($n = 7$)
ISP	stands for innovation system performance
I	stands for an innovation outcome
*	means logical 'and'
→	denotes a sufficient condition, as in X implies Y, X is sufficient for Y
←	denotes a necessary condition as in Y implies X, X is necessary for Y

QCA methods permit testing whether all conditions are necessary and sufficient for innovation to occur. Studies can directly measure data on the conditions that the S and F theories define; similarly, studies can measure the occurrence of innovation as a case outcome. Scholars can only infer the intermediate outcome of ISP from the occurrence of innovation.

3. Methods

This study tests the two IS theories using multiple case studies within a single sector and technology. The choice of food safety innovation in the Australian red meat sector as the case study is because this sector is at the intersection of SIS and TIS, and because of this sector's critical importance in food security. The cases were projects in which managers expected some change (innovation) at the commencement of the project and in which the research phase concluded successfully more than 2 years before the date of data collection. The study used internal records of Meat & Livestock Australia (MLA) as a basis to define the projects and the actors involved. Every project meeting the case definition was included in the study.

An on-line survey provided the data. The survey instrument asked questions to determine whether innovation occurred, and the strength of the conditions that the two IS theories identified. The study identifies innovation by adapting the OECD (2005) typology to the sectoral and technological domain. The measurement of IS conditions in the project used formative scales (Covin & Wales, 2011) drawing on responses to several statements using a 7-point Likert scale (except for actor competence which used a 3-point scale) to build on the definitions and explanations of previous scholars adapted to the domain (Arrow, 1962; Bergek et al., 2008; Cagnin et al., 2012; Hekkert et al., 2007; Klein Woolthuis, 2010; Klein Woolthuis et al., 2005; Pitt & Nelle, 2008; van Mierlo et al., 2010; Weber & Rohracher, 2012; Wieczorek & Hekkert, 2012). The measure that the study uses is the consensus response of all respondents. The study applies fuzzy set QCA (fsQCA) methods (Rihoux & Ragin, 2009; Schneider & Wagemann, 2010; 2012) using fsQCA software version 2.5 (Ragin & Davey, 2014).

4. Findings

The survey results form a dataset on 41 projects with 239 responses from 100 respondents (some respondents provide data on more than one project). Over 92% of surveys provide substantially complete data. The program manager at MLA provides additional data for all projects and represents 15.7% of all responses; less than half (43%) of the responses came from researchers in the projects.

For testing theory, fsQCA is useful for reviewing the relationship between conditions and outcomes, constructing truth tables, suggesting relevant causal configurations through logical minimization, and reporting the consistency and coverage of those configurations. For each condition in the two theories and the innovation outcome, the study uses a single measure building on responses to several statements using a Likert scale (Table S1).